

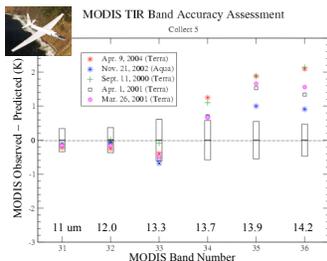
# Assessing MODIS CO<sub>2</sub>-Sensitive LWIR Band Calibration Accuracy

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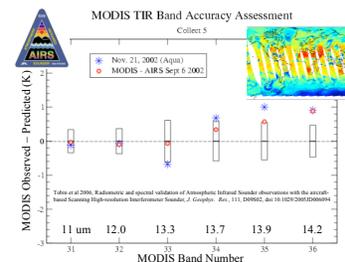


## LIB Validation Findings: Aircraft to MODIS



ER-2 based SHIS and MAS comparisons to Terra and Aqua MODIS Collection 5 LIB have shown that the calibration of bands 34-36 has been persistently too warm.

## LIB Validation Findings: AIRS to MODIS



Satellite based comparisons of Aqua AIRS to MODIS have shown that the calibration of bands 34-36 is warm, and are in close agreement with the ER-2 aircraft based findings for Aqua MODIS.

**OBJECTIVE:** Gain understanding on the radiometric performance of MODIS LWIR CO<sub>2</sub> bands through assessing various components of the calibration algorithm.

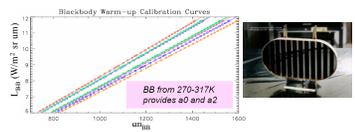
**Problem:** MODIS CO<sub>2</sub>-sensitive bands 34-36 have shown persistent out-of-specification radiometric behavior on Terra and Aqua as shown by aircraft (left) and satellite (right) based comparisons.

**Study:** Review the MODIS LIB calibration algorithm factors to look for possible contributions to out-of-specification behavior. Consider the uncertainty information available and anecdotal evidence to help identify offending factors.

### Summary

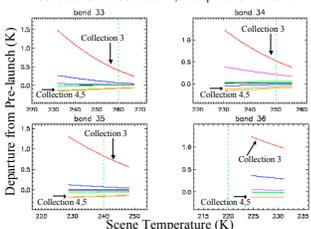
- Aqua MODIS CO<sub>2</sub> bands 34-36 show warm calibration bias to standard of about 0.5 to 1.0 K. Terra MODIS bias is approximately double of Aqua MODIS for bands 34-36. What factors cause this calibration bias?
- 1) The A<sub>0</sub> calibration coefficient was already adjusted for Collection 4 and 5 so that post-launch calibration matches pre-launch calibration to within about 0.2 K for all scene temperatures. No more adjustment envisioned.
  - 2) Increasing optical cross talk correction on Terra MODIS causes a-physical features in imagery.
  - 3) The scan mirror term uncertainty has been stated as small, but on-orbit evaluations suggest it may be underestimated.
  - 4) Out-of-band (OOB) radiometric measurements were very poor quality. Cannot be eliminated as major influence.
  - 5) Spectral characterization uncertainty is smaller than required adjustment to remove calibration bias.
  - 6) The additive bias of these factors does not match the observed bias of MODIS. OOB remains an unknown in the error budget.
- Other systematic influences (scan mirror temp., BB emissivity/temp., scan cavity emissivity/temp.) are expected to be small (<0.1 K).

## 1. On-orbit Calibration Coefficients



Radiance (TOA), L<sub>TOA</sub> =  $\frac{1}{R_{TS}} (a_0 + b_1 \sin_{\theta} + a_2 \sin_{\theta}^2 - (R_{TS_{\theta}} - R_{TS_{\theta}}) L_{BB})$   
 RVS: Response Versus Scan-angle  
 # Emissivity  
 # Spectral band averaged radiance  
 # background corrected digital count

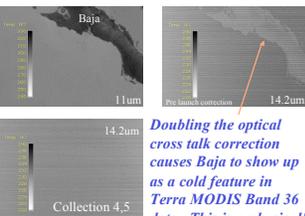
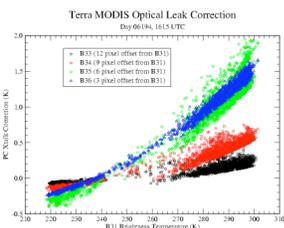
Terra MODIS CO<sub>2</sub>-Sensitive LWIR Band Calibration  
 Collection 3 and Collection 4,5 compared to Pre-launch



For Collection 4 and 5, the A<sub>0</sub> term (offset) was already set to zero to improve the match of MODIS post-launch calibration to pre-launch calibration for bands 33-36, especially for cold scenes. The pre-launch calibration is considered to be the most robust calibration of MODIS.

## Survey of Possible Contributors to MODIS Calibration Bias

### 2. Terra-only Optical Cross Talk



MODIS Band	33	34	35	36
1. Calibration Coefficients	0.1 K	0.1	0.2	0.2
2. Optical Cross talk (Terra)	0.2 K	0.3	0.4	0.5
3. Scan Mirror Reflectance	0.1 K	0.1	0.1	0.2
4. Filter Leaks (OOB)	?	?	?	?
5. Spectral Characterization	0.2 K	0.2	0.2	0.3
Additive Bias (Terra)	+/-0.6 K	+/-0.7	+/-0.9	+/-1.2
ER-2 Terra Bias	-0.37 K	0.93	1.74	1.77
Additive Bias (Aqua)	+/-0.4 K	+/-0.4	+/-0.5	+/-0.7
ER-2 Aqua Bias	-0.68 K	0.68	1.00	0.91

### 3. Scan Mirror Reflectance (RVS)

The calibration equation includes RVS terms:

$$L_{TOA} = \frac{1}{R_{TS}} (a_0 + b_1 \sin_{\theta} + a_2 \sin_{\theta}^2 - (R_{TS_{\theta}} - R_{TS_{\theta}}) L_{BB})$$

Uncertainty based on variation of RVS for 10 detectors of each band:

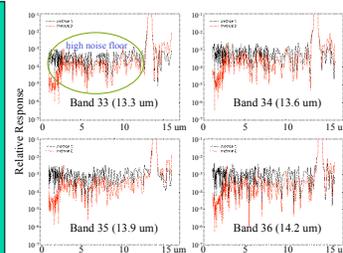
- Band 34: .0058 (<0.10 K)
- Band 35: .0046 (<0.10 K)
- Band 36: .0054 (<0.15 K)

**Caveat!** On-orbit evaluations, including DSM, have significantly changed and improved upon the Terra MODIS pre-launch RVS characterization.

The uncertainty of the scan mirror reflectance is limited to residuals of fitting coefficients for each band. The Terra Deep Space Maneuver (DSM) RVS changed the MODIS calibrated radiances for band 36 by more than 1 K, and by lesser amounts for bands 34, 35.

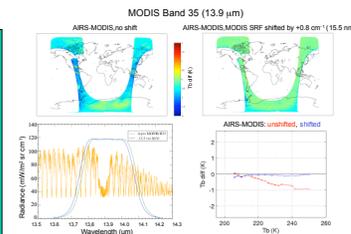
These contributions to MODIS calibration error are approximations based largely upon pre-launch and on-orbit uncertainty analysis. For bands 35 and 36, the additive approximations do not explain the entire MODIS bias for Terra or Aqua. The OOB uncertainty is unknown because the pre-launch measurement data quality was poor. This unknown contribution may be important, but cannot be verified.

### 4. Out-of-Band Filter Leaks



**Problem:** The noise floor of this data is too high to gain useful knowledge about OOB influence on MODIS CO<sub>2</sub>-Sensitive LWIR bands.

## 5. Spectral Characterization



### Pre-Launch RSR Uncertainty Analysis

Band Number	Wavelength (nm)	Measurement Error <sup>1</sup>	SPMA Absolute Wavelength Uncertainty	Temperature Shift on Wavelength	RSS 1-Sigma Wavelength Uncertainty (%)	RSS 1-Sigma Wavelength Uncertainty (nm)	Tobin et al spectral shift to match MODIS and AIRS (nm)
31	11016.4	0.43%	0.25%	0.23%	0.55%	6.1 nm	-----
32	12030.2	0.10%	0.25%	0.15%	0.31%	3.7 nm	-----
33	13363.1	0.06%	0.25%	0.15%	0.30%	4.0 nm	-----
34	13681.5	0.09%	0.25%	0.15%	0.31%	4.2 nm	-15.0 nm
35	13912.7	0.05%	0.25%	0.15%	0.30%	4.2 nm	-15.5 nm
36	14196.5	0.19%	0.25%	0.15%	0.35%	5.0 nm	-20.2 nm

<sup>1</sup> - based on variation in the five spot filter measurements  
<sup>2</sup> - based on comparison with forward model CO<sub>2</sub> absorption feature at 13890 nm.  
<sup>3</sup> - assumed to be 1/3 of correction amount

It has been found using AIRS and MODIS comparisons that shifting the MODIS RSR position could explain nearly all of the radiometric offset between AIRS and MODIS as well as remove the scene temperature dependence in the bias. However, pre-launch estimates of RSR uncertainty do not support the spectral shift size indicated in the AIRS-MODIS comparisons (col 7,8 in table above).